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The International GNSS Servic (IGS): Development and Achiever nts since 1991

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California Institute of Technology (CalTe
1200 E California Boulevard
Pasadena, California 91125
USA

Content

- Handover from Ivan Mueller's introduction
- The IGS Campaign Oversight Committee (1991-1993) and the 1992 IGS test campaigns
- The IGS as an official IAG (International Association of Geodesy) Service
- The IGS Network
- The IGS as an interdisciplinary service
- From the International GPS Service to the International GNSS Service (or: the role of GLONASS in the IGS)
- [The IGS MGEX – Multi-GNSS Experiment → presentation by Oliver Montenbruck]
- [The IGS Real-Time Service → Session PY03, chair Mark Caissey]
- Summary

Motivation for the IGS in 1989

- The primary motivation in planning the IGS was the recognition in 1989 that the most demanding users of the GPS satellites, the geophysical community, were purchasing receivers in exceedingly large numbers and using them as more or less black boxes, using software packages which they did not completely understand, mainly for relative positioning.

- The other motivation was the generation of precise ephemerides for the satellites together with by-products such as Earth orientation parameters and GPS clock information.

The IGS Campaign Oversight Committee

Date	Event
August 1989	IAG Scientific Assembly in Edinburgh. Plans by Mueller, Mader, Melbourne, Minster, and Neilan
March 1990	IAG Executive Committee Meeting in Paris decides to establish a Working Group to explore the feasibility of an IGS under IAG auspices. I.I. Mueller was elected as chairman.
April 1990	The Working Group is redesignated as *IAG Planning Committee for the IGS* in Paris
September 1990	Planning Committee Meeting in Ottawa. Preparation of the *Call for Participation*
February 1991	CFP mailed. Letters of Intent due 1 April 1991
April 1991	CFP Attachments mailed to those whose letters of intent were received
May 1991	Proposals due
June 1991	Proposals evaluated and accepted in Columbus, Ohio
August 1991	Planning Committee reorganized and renamed as *IGS Campaign Oversight Committee* at the 20th IUGG General Assembly in Vienna
October 1991	First IGS Campaign Oversight Committee Meeting in Greenbelt

My report starts with the 20th IUGG General Assembly.

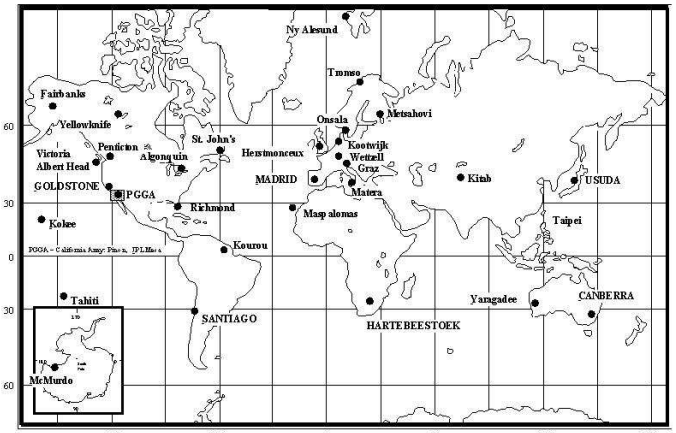
The IGS Campaign Oversight Committee

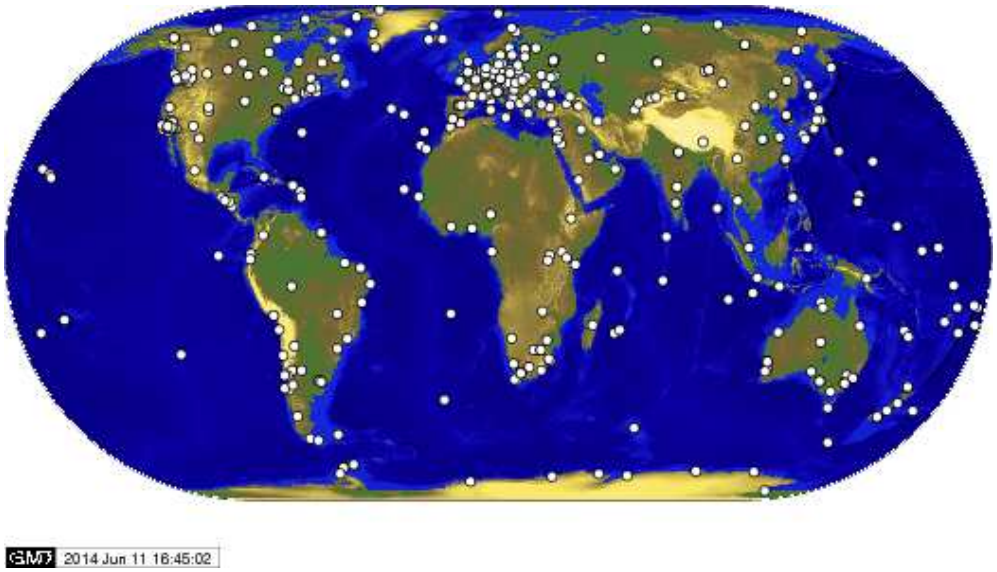
Date	Event
March 1992	2nd IGS OSC Meeting at OSU, Columbus, Ohio
May 1992	Communication test
May 1992	Establishment of IGS Mailbox at University of Bern
June 21, 1992	Start of IGS Test Campaign 1992
July 1992	First results!
July 27, 1992	Start of Epoch'92 campaign, lasting for two weeks
September 23, 1992	Official end of the campaign, continuation on best effort basis
November 1992	Start of IGS Pilot Service
March 1993	1st IGS Workshop in Bern, IGS Terms of Reference drafted
May 1993	Meeting of the OSC in Baltimore
August 1993	IAG Approval for IGS at IAG Scientific Meeting in Beijing
October 1993	IGS Analysis Center Workshop
October 1993	IGS Network Operations Workshop and First Governing Board Meeting
December 1993	2nd Governing Board Meeting in San Francisco

It was probably the most important decision for the IGS *not* to interrupt tracking and analysis on September 23, 1992, but to continue operations on a "best effort basis" after the test campaign.

The terms were drafted in my office at the University of Bern with Ivan breathing down my neck; they were discussed and accepted by the Campaign Oversight Committee in the meeting room of the faculty of Natural Sciences of the University of Bern.

The IGS Tracking Network





From about 20+ receivers (mainly ROGUEs) in 1992 to 400+ receivers in 2014 (“Earth with measles”).

The Official IAG Service 1994 - 2004

Date	Event
January 1994	Start of official service on January 1
November 1994	Workshop on the *Densification of the ITRF* at JPL, Pasadena
May 1995	IGS Workshop on *Special Topics and New Directions* at GFZ in Potsdam
March 1996	IGS Analysis Center Workshop in Silver Spring, USA
March 1997	IGS Analysis Center Workshop at JPL in Pasadena
December 1997	IGS Retreat in San Francisco
February 1998	IGS Analysis Center Workshop at ESOC in Darmstadt
December 1998	Prof. Christopher Reigber elected as IGS Chairman 1999-2002
March 1999	LEO Workshop, Potsdam, Germany
June 1999	Analysis Center Workshop, La Jolla, California
March 2000	IGS Tutorials in South Africa
May 2, 2000	Selective Availablitiy removed!!
July 2000	IGS Network Workshop
July 15, 2000	CHAMP Launch
September 2000	IGS Analysis Center Workshop at USNO
December 2000	IGS Strategic Planning Meeting
February 2001	LEO Workshop
March 2001	Glonass Service Pilot Project
March 2001	TIGA Project established
April 2002	Ottawa Workshop: Towards Real-time
July 2002	UN Regional GNSS Workshop
December 2002	Prof. John Dow elected as IGS Chairman 2003-2006
April 2003	Ionosphere maps (IONEX) etc. official IGS product
May 2003	First operational combined GPS/GLONASS analysis products
August 2003	Essential improvement of “near-real-time” orbits
March 2004	IGS Analysis Center Workshop and 10 Years Symposium

Orbit Validation / Combination

Bulletin Géodésique (1995) 69:200–222

Bulletin Géodésique

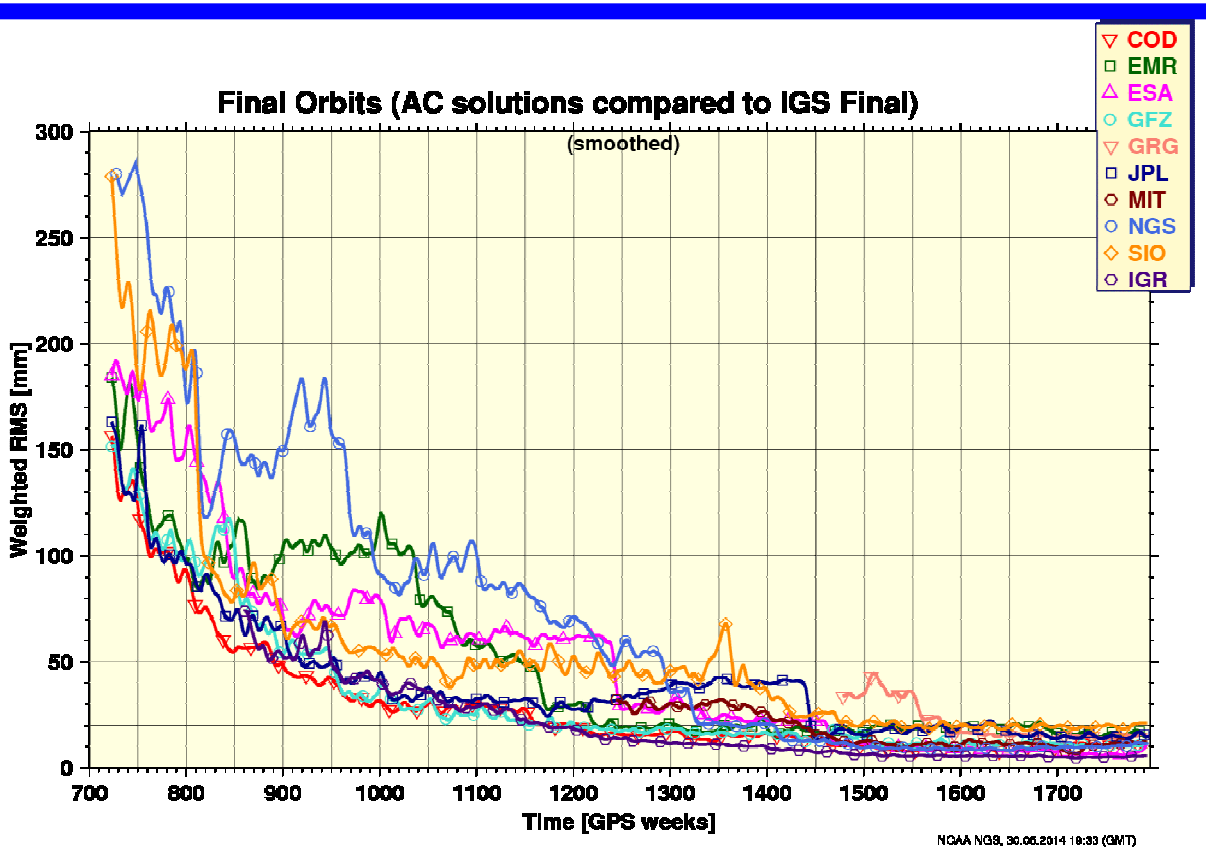
Combining the orbits of the IGS Analysis Centers

Gerhard Beutler [1], Jan Kouba [2], and Tim Springer [3]

[1] Astronomical Institute, University of Bern, Bern, Switzerland
[2] Geodetic Survey of Canada, SMRRS, NRCan, Ottawa, Canada
[3] Delft University of Technology, Delft, The Netherlands

Principles of orbit combination – basically still in use today.
Quote from Jan Kouba when the IGS Combination was accepted by the IGS GB:
Oh, Gerhard, they really bought that!

Orbit Validation / Combination



Consistency of Analysis Center Contributions to the combined IGS final orbit (from January 1994 to 2014).

The IGS as an interdisciplinary service

The GNSS observable enables interdisciplinarity:

Navigation: $c\,(t_r - t^s) = \rho + c\,(\Delta t_r - \Delta t^s) + \Delta\rho_I(\lambda) + \Delta\rho_t$

Science: $c\,(t_r - t^s) = \rho + c\,(\Delta t_r - \Delta t^s) + \Delta\rho_I(\lambda) + \Delta\rho_t$

In navigation the grey terms are assumed as known

- $\rho = |r(t^s) - R(t_r)|$ **is used to determine the position of the receiver** $R(t)$**, and the orbit** $r(t)$ **of the GNSS satellite.**
- $c\,(\Delta t_r - \Delta t^s)$ **is used for the synchronization of space and ground clocks.**
- $\Delta\rho_I(\lambda)$**, the ionospheric delay, is used for ionosphere modeling (space weather).**
- $\Delta\rho_t$**, the signal delay in the neutral atmosphere, is used in meteorology (in particular to determine the rapidly varying water vapor content of the atmosphere).**

The IGS as an interdisciplinary service

Pergamon
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THE INTERNATIONAL GPS SERVICE (IGS): AN INTERDISCIPLINARY SERVICE IN SUPPORT OF EARTH SCIENCES

G. Beutler[1], M. Rothacher[1], S. Schaer[1], T.A. Springer[1], J. Kouba[2], R.E. Neilan[3]




IGS colleagues of the first generation!

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The founders: Gerry Mader (CIGNET), William Melbourne, Bernard Minster (Geophysics perspective), Ivan Mueller (Chief ideologist), Ruth Neilan (Ms Casa Uno, Dos, Tres, …, Central Bureau)

IGS Infrastructure & Standards: Angie Moore (network), Carey Noll (CDDIS), Werner Gurtner (RINEX, IGS Reports / Messages), …

Analysis Center Coordination: Clyde Goad, Jan Kouba, Tim Springer, Robert Weber, Gerd Gendt, Jim Ray (the Warrior), Jake Griffiths, Kevin Choi, ???

Chairmen: Gerhard Beutler, Chris Reigber, John Dow, Urs Hugentobler

GLONASS: Jim Slater from NIMA (National Imagery and Mapping Agency)!

The IERS Link (French Connection): Martine Feissel, Claude Boucher (to some extent …), Bernd Richter, Chopo Ma, Pascal Willis, Zuheir Altamimi, …

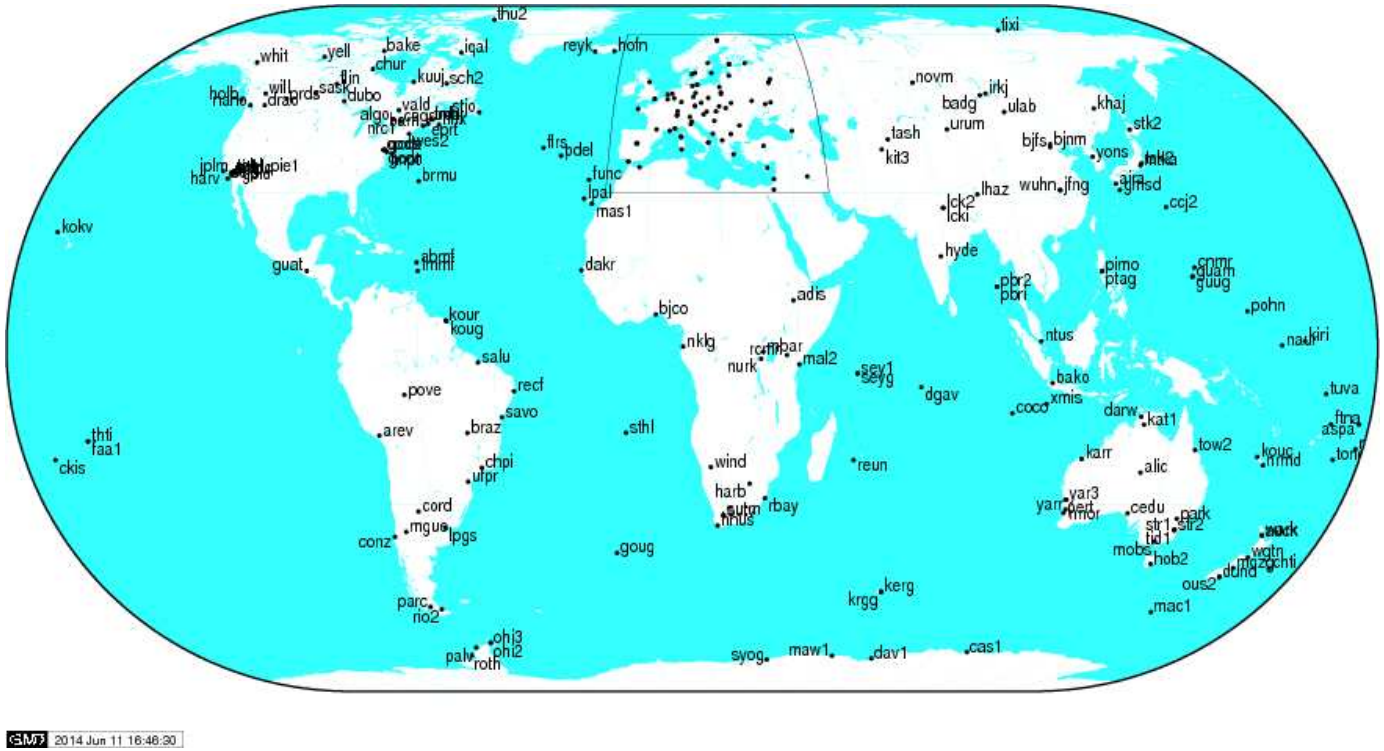
The time keepers: Dennis McCarthy, Jim Ray, Gérard Petit, Félicitas Arias, Ken Senior

… and many other friends and colleagues.

The International GNSS Service

Date	Event
March 2005	IGS renamed International GNSS Service
May 2006	IGS Analysis Workshop in Darmstadt, Germany
December 2007	Combined Space-geodetic analysis workshop in San Francisco, USA
June 2008	IGS Analysis Center Workshop in Miami, USA
2008	IGS Antenna Working Group established
2008 - 2009	First IGS Reprocessing Campaign 1994 - present
2008	IGS Bias and Calibration Working Group
June 2010	IGS Analysis Center Workshop in Newcastle, UK
January 2011	Urs Hugentobler (TU Munich) new IGS Chair
August 2011	IGS-MGEX Call for Participation launched
January 2012	IGS Workshop on GNSS Biases in Bern, Switzerland
July 2012	IGS Analysis Center Workshop in Olsztyn, Poland
2013 - 2014	Second IGS Reprocessing Campaign 1994 - present
June 2014	IGS Workshop and celebration of 20 years of services

The International GNSS Service



2014 Jun 11 16:46:30

IGS Network of combined GPS/GLONASS Receivers

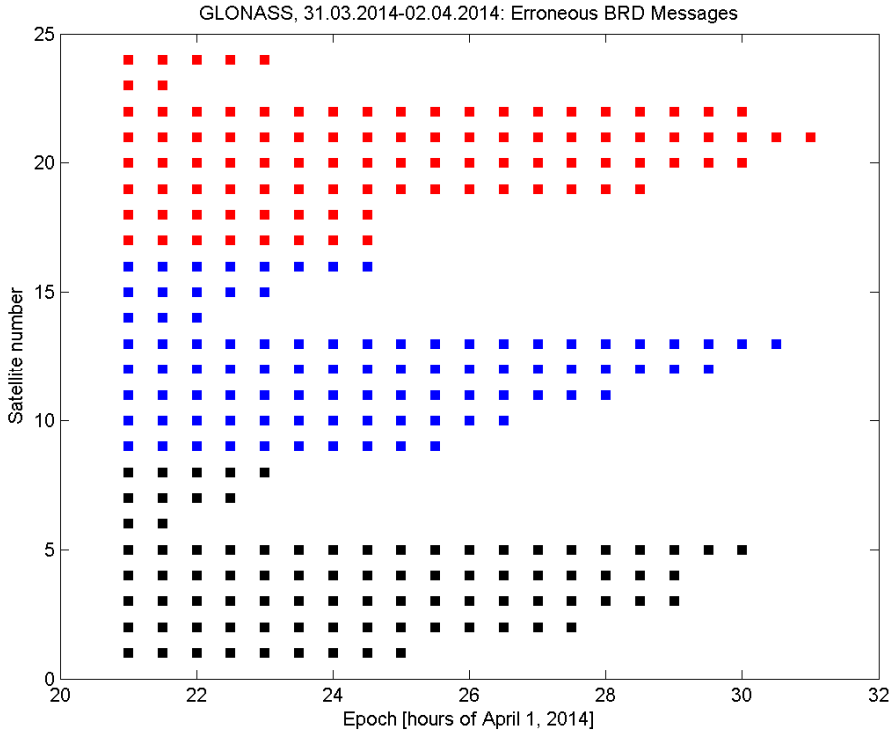
About 300 receivers, individual IGS ACs use up to about 200 sites.

The IGS is the International GNSS Service since 2005.

The International GNSS Service

Site	City	Country	Lat	Lon	Height	Receiver	Antenna		Calibration	Last Data Avail	Satellite System
GODZ	Greenbelt	United States	39.02	-76.83	14.51	JPS EGGDT	AOAD/M_T	JPLA	N/A	24-May-14	GPS GLO
GOL2	Goldstone	United States	35.42	-116.89	986.68	ASHTECH UZ-12	AOAD/M_T	NONE	ROBOT	24-May-14	GPS
GOLD	Goldstone	United States	35.42	-116.89	986.68	JPS EGGDT	AOAD/M_T	NONE	ROBOT	24-May-14	GPS GLO
GOPE	Ondrejov	Czech Republic	49.91	14.79	592.60	TPS NETG3	TPSCR.G3	TPSH	ROBOT	24-May-14	GPS GLO
GOUG	Gough Island	dependent territory of the U.K.	-40.35	-9.88	81.27	LEICA GR10	LEIAR25	LEIT	ROBOT	N/A	GPS GLO GAL BDS
GRAC	Caussols	France	43.75	6.92	1319.80	TRIMBLE NETR9	TRM57971.00	NONE	ROBOT	N/A	GPS GLO GAL BDS SBAS
GRAS	Caussols	France	43.75	6.92	1319.30	TRIMBLE NETR5	ASH701945E_M	NONE	ROBOT	24-May-14	GPS GLO
GRAZ	Graz	Austria	47.07	15.49	538.30	LEICA GRX1200+GNSS	LEIAR25.R3	LEIT	ROBOT	24-May-14	GPS GLO
GUAM	Dededo	Guam	13.59	144.87	201.92	JAVAD TRE_G3TH DELTA	ASH701945B_M	JPLA	N/A	24-May-14	GPS GLO
GUAO	URUMQI	CHINA	43.47	87.18	2049.20	ASHTECH UZ-12	ASH701945B_M	NONE	COPIED	14-Apr-14	GPS
GUAT	Guatemala City	Guatemala	14.59	-90.52	1519.90	LEICA GRX1200GGPRO	LEIAR25.R3	LEIT	ROBOT	24-May-14	GPS GLO
GUUG	Mangilao	USA	13.43	144.80	134.70	TRIMBLE NETR5	TRM55971.00	NONE	ROBOT	24-May-14	GPS GLO
HALY	Halat Ammar	Saudi Arabia	29.14	36.10	861.68	TRIMBLE NETRS	ASH701945C_M	SCIT	FIELD	N/A	GPS
HARB	Pretoria	Republic of South Africa	-25.89	27.71	1555.00	TRIMBLE NETR9	TRM59800.00	NONE	ROBOT	24-May-14	GPS GLO GAL SBAS
HARV	Vandenberg AFB	United States	34.47	-120.68	14.97	JAVAD TRE_G3TH DELTA	AOAD/M_T	JPLA	N/A	15-Jan-14	GPS GLO
HERS	Hailsham	United Kingdom	50.87	0.34	76.50	SEPT POLARX3ETR	LEIAR25.R3	NONE	ROBOT	24-May-14	GPS GLO
HERT	Hailsham	United Kingdom	50.87	0.33	83.30	LEICA GRX1200GGPRO	LEIAT504GG	NONE	ROBOT	24-May-14	GPS GLO
HLFX	Halifax	Canada	44.68	-63.61	3.10	TPS NET-G3A	TPSCR.G3	NONE	ROBOT	24-May-14	GPS GLO

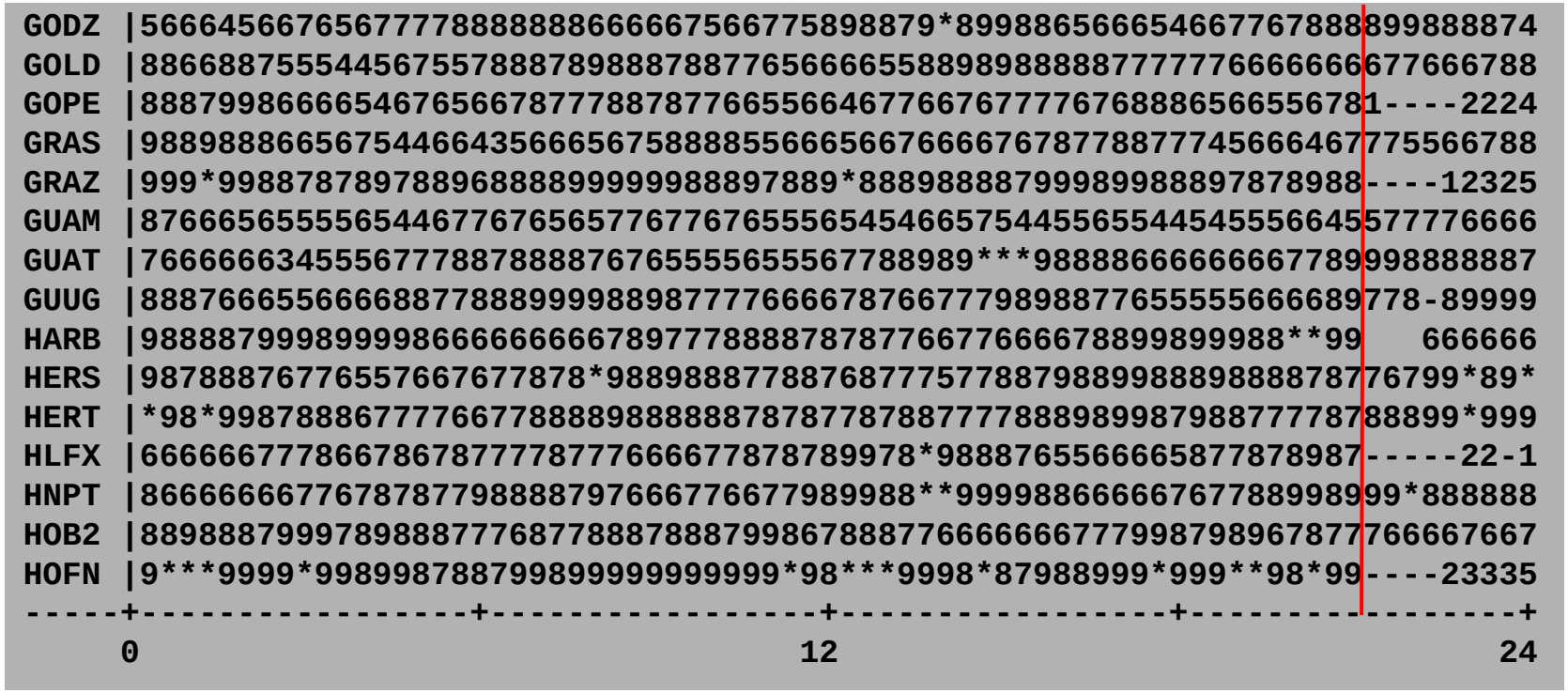
The GLONASS 2014 April 1st Incident in the IGS



Affected GLONASS Broadcast Messages. Satellites 6, 7, 8, 14, 15, 23, 24 back to normal before end of April 1st (UTC).

The transmission of erroneous broadcast messages in essence led to a GLONASS system failure for "normal" users – but not for the IGS

The GLONASS 2014 April 1st Incident in the IGS



 # GLONASS satellites tracked by IGS receivers (from CODE analysis protocol of April 1). Some receivers tracking properly, some stopped tracking GLONASS after 9h p.m. (red line), some even stopped GPS tracking!

Out of about 180 receivers used by CODE, about 60 were severely affected!

The “true value” of the IGS Network

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The IGS maintains a list of sites in its network of 400+ receivers.

The IGS network is heterogeneous (virtually all high precision receiver types), many of them multi-GNSS.

This IGS site list, together with the protocols of the IGS ACs, allowed it to analyze the GLONASS April 1-2 incident in some depth:

- There were three classes of receivers, those tracking normally, those tracking GPS normally, and those failing to track GPS and GLONASS.
- The incident was caused by bad GLONASS Broadcast Messages (BM) transmitted for some time from 9h p.m. onwards.
- The positions from the bad broadcast messages showed a consistent rotation of about 0.5 deg around the x-axis of the inertial equatorial coordinate system.
- More information: (http://www.gps.gov/governance/advisory/meetings/2014-06/beutler1.pdf)

The IGS data (in particular the concatenated Broadcast Messages) was of paramount importance to analyze the effect.

The IGS is in a position to perform an integrity monitoring of all GNSS included.

IGS Products beyond Analysis

- The IGS Central Bureau (e.g., with Angie Moore in the early days) maintains and documents the IGS site list.
- Standardisation (RINEX and SINEX became, e.g., true standards) was and is extremely important.
- Standardisation is going on in IGS Real Time Servive and MGEX!
- The IGS organized a number of retreats and issued a series of strategic plans (the most recent one for 2013-2016)
- The IGS network is a technique-specific contribution to IAG's GGOS (Global Geodetic Observing System).

Summary

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The IGS is based on *user demands* and *needs*.

The IGS is the reference for all GNSS solutions.

The IGS has *redundancy* in network, data centers, analysis.

Today, the IGS truly is a GNSS service.

IGS generates combined products ==> *robustness.*

IGS fully (understands and) exploits the GPS signal ==> stands for *Interdisciplinarity*.

Friendly, but tough competition of analysis centers ==> *Stimulating research & development environment.*

IGS is the *Authority for the scientific exploitation of GNSS*.

The IGS could and can rely on dedicated contributors!

In the 1990s "everything the IGS did" was "cutting edge science"!

Is this still true today? Undoubtedly the emphasis has shifted to attractive applications of GNSS (e.g., LEO orbit determination).

How to react/should the IGS react?